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# Accurate Prediction of Outcome After Pediatric Forearm Fracture

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Summary: Factors affecting outcome after pediatric forearm fracture include fracture angulation and fracture position. A new index, axis deviation, combines these factors. Two review studies were performed to determine if axis deviation correlated with outcome. In the first study, 35 subjects were reviewed 2.7 years after fracture without radiographs. In the second study, 152 fractures were reviewed a mean of 4 years after fracture, with 124 patients consenting to undergo radiographs. In both studies, the new index, axis deviation, correlated better with restricted forearm movement than either degree of angulation or fracture position. Midshaft and distal remodeling occurred and could be predicted in terms of axis deviation. We propose that an axis deviation of <5 at the time of union be the reduction criteria of pediatric forearm shaft fracture regardless of fracture position. Key Words: Angulation—Pediatric forearm fracture—Radius—Ulna—Remodeling.

Previous studies have outlined factors affecting outcome after pediatric forearm fracture. These factors include angulation remaining at the fracture site (3,6,14,15,21), position of the fracture (24), remodeling potential of the bone (8–11) and rotational deformity (5,20) at the fracture site.

Angulation and its effect on outcome has been discussed by Fuller and McCullough (10), Darwulla (6), and the current state of knowledge is summarized in Rockwood, Wilkins, and King (22). Increasing angulation at the fracture site is associated with restricted forearm rotation. In children who are not fully grown, 10° angulation at the midshaft or 25–30° at the distal end is the current limit of acceptable angulation (12,14,15). Larger angulations lead to cosmetically unacceptable deformities in the distal third of the forearm, and restricted forearm motion for fractures in the midshaft (14,15).

In previous studies, angulation was often estimated using the largest angle seen in the anteroposterior (AP) or lateral radiographs of the forearm. The accuracy of measurement of angulation can be improved by using the angulation seen in both radiological views and calculating the true angulation of the fracture site, as described by Barr and Breitfuss (2).

Fracture position has been traditionally classified into proximal third, midshaft and distal categories. Midshaft fractures tend to have the worst outcome of the three, as outlined by Thomas et al. (24). In their study, 39% of midshaft fractures were associated with poor outcome, compared with 31% of the fractures in the distal third (excluding the distal sixth), and 14% in the distal sixth. Other investigators have had similar results (6,18). Although association has been made in the past between fracture position and outcome as well as fracture angulation and outcome, there are many inconsistencies present in the current guidelines for the management of pediatric forearm fracture. If angulation were the sole determinant of outcome, then a midshaft fracture of 10° angulation would be expected to have the same prognosis as a fracture of the same angulation in the distal shaft. Similarly, fracture position alone cannot be used to predict outcome. Angulation and position therefore interact to cause a deformity that results in restricted forearm pronation and supination.

By using a series of geometrical models and hypotheses, we have identified a distance that can accurately define the combined deformity created by angulation and position. This distance, called axis

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deviation, is the distance between the fractured and anatomical axes of the bone analyzed (Fig. 1). The axis deviation is measured at the level of the fracture site. True angulation and fracture position are the input variables. True angulation is calculated from the angulation measured in the two standard radiological views. This calculation is based on the assumption that the two radiological views were taken almost at right angles to each other. This step allows correct assessment of angulation irrespective of the relationship between the plane of angulation and the plane of the radiological views. The axis deviation is described as a percentage of the total bone length, as bone length varies among subjects. This also allows the same subject to be followed throughout growth. The basic steps in the calculation of axis deviation are outlined in Fig. 2. A more complete description of the axis deviation index is described elsewhere (26).

Remodeling occurs in fractures positioned in the distal part of the forearm. Frieburg (8,9), Hogstrom et al. (12), and Ghandi et al. (11) have all shown this to be a clear clinical entity. Ghandi has reported some subjects in which deformities of 30° have corrected themselves. Midshaft remodeling has been shown to occur in dogs (13) and baboons (1). Human midshaft remodeling has yet to be demonstrated.

The first aim of this study was to determine if axis deviation would predict outcome after pediatric forearm fracture more accurately than fracture true angulation or fracture position alone. Our second aim was to determine if the midshaft remodels, and, if so, to describe the remodeling potential of the pediatric forearm shaft in terms of axis deviation. Our final aim was to outline criteria for reduction after shaft pediatric forearm fracture.

## MATERIALS AND METHODS

Two studies were performed using axis deviation to assess outcome after pediatric forearm fracture. Both studies were retrospective with clinical review. The first study was performed to describe the axis deviation concept, and it led to the second, larger and more comprehensive review. In both studies, all forearm fractures requiring reduction

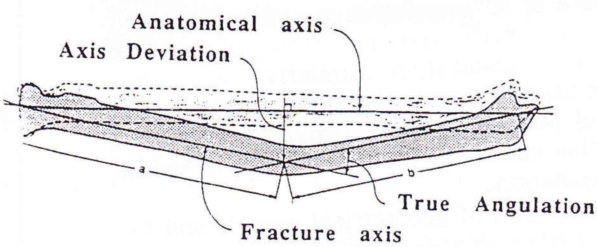


FIG. 1. The concept of axis deviation. The anatomical and fracture axes are diagramatically represented. Axis deviation is measured at the level of the fracture site. Although the radius is curved, the representation is drawn as a straight line. Angulation is measured at the level of the fracture site using the cortex proximal and distal to the fracture.

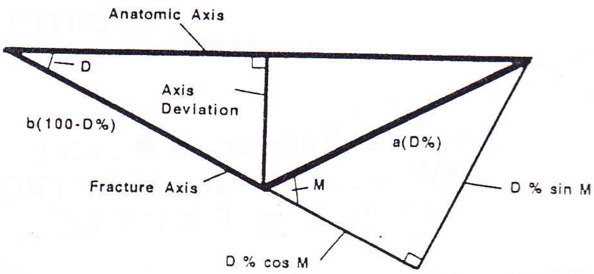


FIG. 2. The mathematical derivation is shown. The anatomical and fracture axes are represented. *M* is the true angulation at the fracture site. The distances *a* and *b* are the distances between the fracture site and each end of the bone measured on plain radiographs. The distance between the fracture site and the end of the bone (*D*%) can be expressed as a percent of total bone length using the equation

$$D\% = a/(a + b) \times 100$$

Axis deviation can be expressed in angle *D* and *D*% as

$$AD = \sin D \times (100 - D\%)$$

The angle *D* can be determined using the equation

$$D = \operatorname{atan}((D\% \times \sin M)/((D\% \times \cos M) + (100 - D\%))$$

were reviewed, excluding physeal fractures of the distal radius.

Study 1 was derived from a review of the records of 217 pediatric forearm fractures requiring closed reduction from 1982 to 1985. The angulation of the radius in the AP and lateral planes was measured using the radiographs taken at the time of union (or cast removal). Eighty-eight patients had >10° of angulation on at least one of the views. These patients were asked to attend review; 35 of the patients returned and were examined. The range of pronation and supination of both forearms was examined, including the range of wrist and elbow motion. No follow-up radiographs were taken. Group one, therefore, was preselected by angulation of the fracture site at completion of treatment. The results were used to compare axis deviation at the time of union with the range of motion at review.

Study 2 was a review of 150 children with 152 forearm fractures requiring closed reduction between 1980 and 1987. A total of 368 fractures were reduced in this period. Of this study group, 124 patients consented to radiographic examination at review, an average 4 years from fracture. As in the first study, the range of pronation and supination of both forearms was examined along with the range of wrist and elbow movement. This portion of the study evaluated the axis deviation's ability to document remodeling of the bone, and was used to further outline the limit of acceptable deformity at the time of union.

Axis deviation was calculated for the radius alone for both studies. It was felt that the radius was the more likely to impinge during the arc of pronation and supination, and that the ulnar deformity would be similar to the radial deformity. In the second study, there was a correlation seen between the angulation measured on the radius and the ulna, with an $r^2$ value of 0.516. We attempted to assess radiological malrotation using Milch's criteria (16), but found it to be an unreliable technique.

In both this section and the Results, measured angulation refers to the largest angulation seen on one radiological view. True angulation is the calculated angulation at the fracture site. Axis deviation is the calculated distance between the anatomical and deformed axes of the radius, and is expressed as a dimensionless unit, being a percentage of the total bone length. Fracture position refers to the point along the length of the radius where the fracture lies. This is also expressed as a percent value, with the radiocarpal joint lying at 0% and the radial head at 100%. Distal third fractures are those fractures between 0 and 33% (excluding physeal injuries), and midshaft are injuries lying between 33 and 66%. Forearm rotation refers to the range of pronation and supination, with restriction being a decrease on the injured side compared with the contralateral side.

### Statistical analysis

In study 1, three sets of statistical analyses were performed. The patients were categorized into two subgroups: those with restriction of pronation or supination and those with normal movement. Restriction was defined as a decrease of pronation or supination >10° in the injured arm compared to the contralateral arm (21).

Using a single-factor analysis of variance (ANOVA), the mean value of measured angulation and axis deviation of the subgroups was compared. A larger difference between these subgroups indicated the measure used would have more powerful predictive ability at the time of union as to the long-term prognosis. A second statistical analysis used simple regression and analysis of covariance (ANCOVA) to correlate the degree of restriction of movement with measured angulation, axis deviation, true angulation, and fracture position. The measure with the largest correlation coefficient would be the best determinant of outcome.

In study 2, ANOVA and ANCOVA were used to assess factors correlating to restriction of motion at time of review (Fig. 3). These included axis deviation, true angulation (measured at time of cast removal and time of review), fracture position, and severity of the injury as assessed by the magnitude of axis deviation at the time of presentation. Remodeling was assessed using the improvement of axis deviation or true angulation from the time of cast removal to time of follow-up. Significance was taken at $p < 0.05$.

### Demographic data

In study 1, 19 boys and 16 girls were examined. The length of time between fracture and follow-up examination averaged 2.9 years (range 2–5 years). Of these children, 11 (7 boys, 4 girls) had restricted forearm rotation averaging 22.7° (range 10–100°). The restricted movement subgroup had a mean age of 7.2 years, with a mean time since fracture of 2.9 years. Eight children had fractured both bones of the forearm, and three a single bone. Seven fractures were midshaft, and four were distal. In the 12 boys and 12 girls comprising the subgroup with normal forearm rotation, the mean age was 8.1 years, and the mean time since fracture was 2.9 years. Eleven children had midshaft fractures, and 13 had distal fractures. Thirteen patients had fractured both bones, and 11 a single bone.

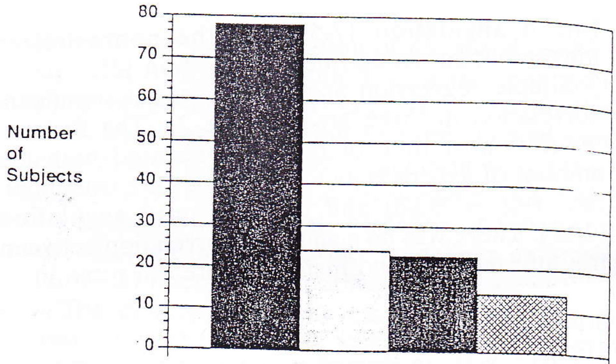


FIG. 3. Distribution of restriction for study 2. Left to right: black bar indicates restriction of −10°; light gray bar indicates restriction of 10–20°; dark gray bar indicates restriction of 20–30°; cross-hatched bar indicates restriction of 30°.

In study 2 (95 boys, 55 girls) the mean age at fracture was 8.1 years (range 1–16 years). Eighty-seven fractures were on the left and 65 were on the right, with two bilateral. The mean time between fracture and review was 4.6 years (range 2–9 years). One-hundred fractures were in the distal third, 33 were in the midshaft, and four in the proximal third.

## RESULTS

### Study 1

Using a single-factor ANOVA (Table 1), the axis deviation at time of cast removal showed a significant difference between the restricted movement subgroup (axis deviation mean 6.9) and the nonrestricted subgroup (axis deviation mean 4.9). The measured angulation showed no significant difference between the restricted movement subgroup

TABLE 1. *Single-factor ANOVA of restricted and nonrestricted groups at time of cast removal*[a]

| | Axis deviation | True angulation |
|---|---|---|
| Restricted movement | 6.87 ± 3.04 | 17.46 ± 6.11 |
| Nonrestricted | 4.87 ± 2.21 | 15.0 ± 5.66 |
| *F* value | 4.86 | 1.35 |
| *p* value | <0.05 | >0.1 |

[a] From Study 1.

(mean angulation 17.5°) and the nonrestricted movement subgroup (mean angulation 15°).

Simple regression analysis showed a significant correlation in three areas (Table 2). The forearm restriction at time of review correlated with the amount of axis deviation ($r = 0.71$), the true angulation ($r = 0.68$) and the measured angulation (0.65). There was no significant correlation between fracture position and restricted forearm rotation.

### Study 2

There was an overall significant restriction of forearm rotation on the injured side compared to the noninjured side (186.6° compared with 195.5°). The injured side had lost an average of 8.9°. Only one subject complained of loss of forearm rotation. This subject was 14 years old at time of injury and had a midshaft injury to both bones with a 50° restriction in rotation. The only factor that significantly correlated with restriction of rotation was axis deviation at time of review ($r = 0.19$). Factors not correlated with restriction at time of review included axis deviation at the time of cast removal, true angulation (at time of review and at time of cast removal), fracture position, and initial displacement as assessed by magnitude of axis deviation at time of presentation (Table 3).

Remodeling was assessed using improvement in both the axis deviation and the true angulation: The mean improvement of axis deviation was 1.73. This decrease from 2.71 at time of cast removal to 0.98 at time of review indicated remodeling had taken place. The improvement in axis deviation following a midshaft fracture was 1.76; following a distal fracture, it was 1.67, with no statistical difference between the two. Using true angulation, the distal fractures improved by a mean of 8.6° and the midshaft fractures improved a mean of 4.4°. This difference was significant (Fig. 4).

There was no relationship between the degree of displacement at time of injury (assessed by axis deviation at time of injury) and restriction of forearm motion. However, the axis deviation at time of presentation correlated to the axis deviation at time of cast removal. This suggested a trend in which severe injury leads to a less perfect reduction and a greater degree of remodeling.

TABLE 2. *Simple regression analysis of degrees of restriction of forearm movement and the values for axis deviation, true angulation, maximum angulation, and fracture site*[a]

| | Axis deviation | True angulation | Maximum angle | Fracture site (*D%*) |
|---|---|---|---|---|
| $r$ | 0.71 | 0.68 | 0.65 | 0.38 |
| $r^2$ | 0.50 | 0.46 | 0.43 | 0.14 |
| $F$ test | 8.99 | 7.52 | 6.69 | 1.82 |
| $p$ | <0.05 | <0.05 | <0.05 | >0.1 |

[a] Data extrapolated from 11 subjects in the restricted movement group in Study 1.

TABLE 3. *Correlation between restriction of forearm movement and axis deviation*[a]

| Factor | $r$ | $r^2$ | $F$ | $p$ |
|---|---|---|---|---|
| Axis deviation at review | 0.19 | 0.04 | 4.19 | <0.05 |
| True angulation at review | 0.17 | 0.03 | 3.43 | >0.05 |
| Age of patient | 0.14 | 0.02 | 2.70 | >0.05 |
| Axis deviation of injury | 0.10 | 0.01 | 1.18 | >0.05 |
| Axis deviation at union | 0.05 | <0.01 | 0.36 | >0.05 |
| Malrotation at union | 0.09 | <0.01 | 1.07 | >0.05 |
| True angulation at union | 0.04 | <0.01 | 0.20 | >0.05 |
| Fracture position | 0.01 | <0.01 | 0.01 | >0.05 |

[a] From Study 2.

## DISCUSSION

The axis deviation, by combining true angulation and fracture position, may be of use in the practical management of fractures. The aim of management is to reduce the fracture so that after remodeling has occurred, no significant restriction of forearm motion is seen. An axis deviation of ≤2 at review [being 0.99 + 1 standard deviation (SD) in our review] would be an acceptable limit. As a remodeling po-

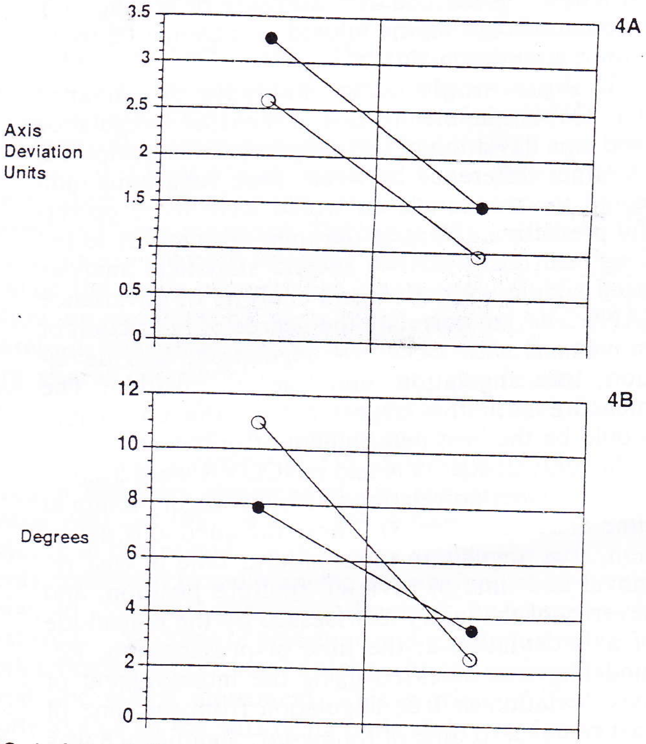


FIG. 4. **A and B:** True angulation and axis deviation at union and review for study 2 subjects. Axis deviation **(A)** shows the remodeling potential (the slope of the graph) to be the same for midshaft and distal fractures. Angulation **(B)** shows a greater degree of remodeling for proximal than distal fractures. Filled circles indicate axis deviation and angulation midshaft, and open circles indicate axis deviation and angulation distal.

TABLE 4. *Correlation between remodeling and axis deviation*[a]

| Factor | $r$ | $r^2$ | $F$ | $p$ |
|---|---|---|---|---|
| Axis deviation at union | 0.81 | 0.66 | 213.99 | <0.05 |
| Axis deviation at injury | 0.22 | 0.05 | 5.72 | <0.05 |
| Axis deviation at review | 0.19 | 0.04 | 4.08 | <0.05 |
| Age at fracture | 0.13 | 0.02 | 1.18 | >0.05 |
| Position of fracture | 0.09 | 0.01 | 0.94 | >0.05 |
| Years since fracture | 0.08 | 0.01 | 0.65 | >0.05 |

[a] From Study 2.

tential of 1.72 was seen (with an SD of 1.68), an axis deviation remodeling of ~3 could be expected. Therefore, an axis deviation of ≤5 at time of cast removal should result in a good outcome.

The axis deviation criteria of 5 corresponds to a true angulation of 10° in the midshaft, 12.5° at the junction of the middle and distal thirds, 20° in the middle of the distal third, and 25° at the subphyseal level of the distal third (Fig. 5B). This is consistent with the cadaver study of Matthews et al. (15), in which angulation of <10° in the midshaft (corresponding to an axis deviation of 5) caused no significant restriction of forearm rotation, and angulation of >20° (axis deviation of 8) caused a 30% restriction of forearm motion, or a 60° reduction in range of movement. Kay et al. (14) found that midshaft fractures in the adult forearm showed significant restriction if > 18° angulation was present, with restriction of pronation/supination of ≤45° at 5-year follow-up. An axis deviation of 5 also corresponds with the appropriate guidelines determined for distal fracture reduction (3,22).

The concept of displacement of the bone axis away from the anatomic axis has been used previously in adult orthopaedics. The distance between the mechanical and anatomical axes of the lower limb at the level of the knee joint is used to determine the required correction in total joint replacement (23). Bowen (4) used a similar index combining angulation and fracture position to determine the need for reduction after fracture of the fifth metacarpal. Therefore, the combination of fracture site position and true angulation to determine the axis deviation of the radius after forearm fracture appears to be a logical step in the prediction of outcome.

The first study showed a correlation between true angulation and restriction of forearm rotation. This

5A

GREATER DISTANCE (cm)

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2.0 | 4.0 | 6.0 | 8.0 | 10.0 | 12.0 | 14.0 | 16.0 | 18.0 | 20.0 | 25.0 | 30.0 | 35.0 | 40.0 | |
| | 50.0 | 33.3 | 25.0 | 20.0 | 16.7 | 14.3 | 12.5 | 11.1 | 10.0 | 9.1 | 7.4 | 6.3 | 5.4 | 4.8 | 2 |
| xxx | | 50.0 | 40.0 | 33.3 | 28.6 | 25.0 | 22.2 | 20.0 | 18.2 | 16.7 | 13.8 | 11.8 | 10.3 | 9.1 | 4 |
| | xxx | | 50.0 | 42.9 | 37.5 | 33.3 | 30.0 | 27.3 | 25.0 | 23.1 | 19.4 | 16.7 | 14.6 | 13.0 | 6 |
| | | xxx | | 50.0 | 44.4 | 40.0 | 36.4 | 33.3 | 30.8 | 28.6 | 24.2 | 21.1 | 18.6 | 16.7 | 8 |
| | | | xxx | | 50.0 | 45.5 | 41.7 | 38.5 | 35.7 | 33.3 | 28.6 | 25.0 | 22.2 | 20.0 | 10 |
| 2 | 2.8 | | | xxx | | 50.0 | 46.2 | 42.9 | 40.0 | 37.5 | 32.4 | 28.6 | 25.5 | 23.1 | 12 |
| 4 | 4.5 | 5.7 | | | xxx | | 50.0 | 46.7 | 43.8 | 41.2 | 35.9 | 31.8 | 28.6 | 25.9 | 14 |
| 6 | 6.3 | 7.2 | 8.5 | | | xxx | | 50.0 | 47.1 | 44.4 | 39.0 | 34.8 | 31.4 | 28.6 | 16 |
| 8 | 8.3 | 9.0 | 10.0 | 11.3 | | | xxx | | 50.0 | 47.4 | 41.9 | 37.5 | 34.0 | 31.0 | 18 |
| 10 | 10.2 | 10.8 | 11.6 | 12.7 | 14.0 | | | xxx | | 50.0 | 44.4 | 40.0 | 36.4 | 33.3 | 20 |
| 12 | 12.2 | 12.7 | 13.4 | 14.3 | 15.5 | 16.8 | | | xxx | | 50.0 | 45.5 | 41.7 | 38.5 | 25 |
| 14 | 14.2 | 14.6 | 15.2 | 16.0 | 17.0 | 18.2 | 19.5 | | | xxx | | 50.0 | 46.2 | 42.9 | 30 |
| 16 | 16.2 | 16.5 | 17.0 | 17.8 | 18.7 | 19.7 | 20.9 | 22.1 | | | xxx | | 50.0 | 46.7 | 35 |
| 18 | 18.2 | 18.4 | 18.9 | 19.6 | 20.3 | 21.3 | 22.3 | 23.5 | 24.7 | | | xxx | | 50.0 | 40 |
| 20 | 20.1 | 20.4 | 20.8 | 21.4 | 22.1 | 22.9 | 23.9 | 24.9 | 26.1 | 27.3 | | | xxx | | |
| 25 | 25.1 | 25.3 | 25.6 | 26.0 | 26.6 | 27.2 | 27.9 | 28.8 | 29.7 | 30.7 | 33.5 | | | xxx | |
| 30 | 30.1 | 30.3 | 30.5 | 30.8 | 31.2 | 31.7 | 32.3 | 32.9 | 33.6 | 34.4 | 36.7 | 39.3 | | | xxx |
| 35 | 35.1 | 35.2 | 35.4 | 35.6 | 35.9 | 36.3 | 36.7 | 37.2 | 37.8 | 38.4 | 40.2 | 42.3 | 44.8 | | |
| 40 | 40.1 | 40.2 | 40.3 | 40.5 | 40.7 | 41.0 | 41.3 | 41.7 | 42.1 | 42.6 | 43.9 | 45.6 | 47.7 | 50.0 | |
| | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 25 | 30 | 35 | 40 | |

GREATER ANGULATION (degrees)

LESSER DISTANCE (cm)

LESSER ANGULATION (degrees)

5B

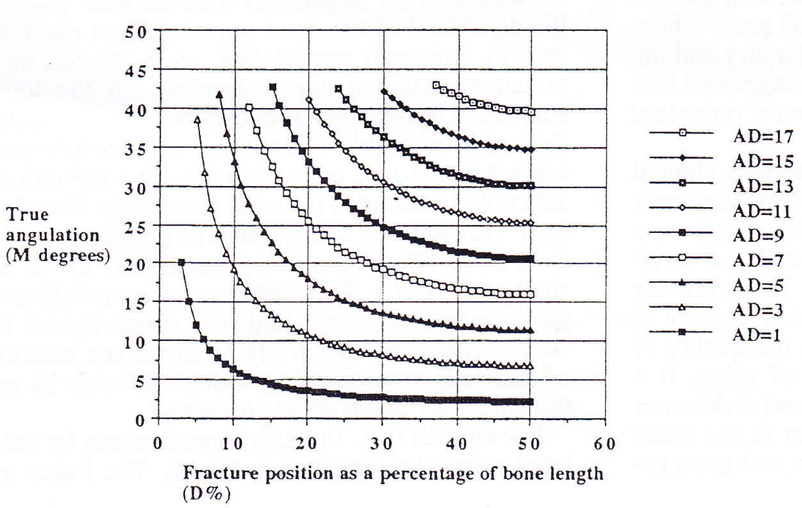


FIG. 5. A and B: Matrices for determining axis deviation. Using the matrix shown in (A), the true angulation (*M*) can be estimated at the lower right-hand corner using the angulation from both radiological views. The lesser angulation is entered on the *X* axis, and the greater angulation on the *Y* axis. *D*% (the position of the fracture as a percentage of bone length) can be estimated at the top right-hand corner of the table by entering the greater distance between the angulation and the bone end on the *X* axis and the lesser distance on the *Y* axis. *D*% will be found at the intercept. These values (*D*% and *M*) are entered in (B). *M* (true angulation) is entered on the *Y* axis and *D*% (position) on the *X* axis. The intercept will lie on the appropriate value for axis deviation. For example, a subject with 20° angulation on one view of a forearm fracture and 18° angulation on the other view will have a true angulation of 26.1°. If the distance between the fracture and each end of the bone is 4 and 10 cm, respectively, the *D*% is 28. Entered on the graph, the intercept lies on the axis deviation line for 9, thus the axis deviation is 9. We feel that all fractures with an axis deviation of >5 should be reduced.

is the first time that this association has been made by statistical analysis. Price et al. (19) expressed doubts about whether angulation is significant; our findings add weight to the argument that it is. However, true angulation has less influence on outcome than axis deviation.

The second group studied had excellent clinical results, with only one subject complaining of restricted forearm movement. In this study, children with minimal deformity and no functional deficit were used to determine the criteria for inadequate reduction. If a group of children with greater deformity at the time of cast removal was studied, then more relationships might have been seen. A relationship between the remodeling potential of the bone and age at time of fracture might also have been seen.

The second clinical group differed from the first in that it was a complete fracture group with no exclusions. The mean age at fracture and fracture patterns were similar to the first group; however, the degree of reduction in forearm motion was much less than in the first group, as was angular malalignment. The larger number of subjects of the second group demonstrated a small (8.7°) but significant difference in forearm rotation between the injured and noninjured sides. The only factor that significantly correlated with restriction was the axis deviation measured at time of review, which presumably reflected the effect of the smaller malalignment in this group. Axis deviation, however, only accounted for a small amount of the variability seen in the group. The effects of soft-tissue damage, scarring of muscles, scarring of the interosseous membrane, and radioulnar joint damage were not considered within the equation. These factors have a variable effect on forearm range of motion. However, as the bony deformity becomes more pronounced, the soft-tissue factors become less significant. Nilsson and Oberant (17) found a mean restriction of 19° of forearm rotation upon reviewing eighteen adults who had suffered forearm fractures in childhood with anatomic reductions. Although initial displacement did not correlate with restriction of forearm motion in our follow-up group, there was a correlation between severity of injury and the axis deviation at cast removal, which suggested that a severe injury leads to a less adequate reduction and a greater degree of remodeling.

Axis deviation criteria can be used in clinical management. In the child whose forearm obviously needs reduction at time of presentation, or when an almost anatomical reduction is achieved and maintained, the calculation is of no value. However, for the child who has a minimally angulated fracture at the time of presentation, or in whom the quality of reduction is questionable, then it is of value. If a loss of reduction occurs in the cast and a decision has to be made about re-reduction, or in the older child who has had a closed reduction and open reduction is contemplated, the axis deviation can be used.

Axis deviation criteria provide a clearly defined limit above which reduction is unacceptable because a poor outcome will likely result. Most of the variables confounding angulation criteria are eliminated. These variables include the angulation seen in the opposite view, changes in magnification, and the management of the regions between the classical thirds of the forearm. In this review, it was observed that many fractures lay between the zones of the forearm, and, therefore, may be inappropriately managed. The division into zones is artificial, does not reflect pathology, and only reflects an estimate of position (25). Axis deviation allows accurate management of the interzones, and allows the whole forearm to be considered as one clinical entity. In clinical management, axis deviation should not be used for physeal fractures, as we feel they are a different clinical entity, and should not be used for proximal fractures, as too few fractures in our study in this zone were seen for deductions to be made.

The concept of true angulation is not new. Floyd (7) showed that single-plane views of the lower limb often lead to inaccurate assessment of angulation deformity because the limb was positioned in variable rotations compared with the x-ray plate. Barr and Breitfuss (2) demonstrated a method by which the true angulation of a fracture site could be determined. This method was similar to the one used in our study, with both being based on trigonometry and the assumption of 90° orthogonal views. Variable rotation between views can also occur during follow-up of a pediatric forearm fracture, making it difficult to assess whether reduction has been lost or the angulation is the same and a different view has been taken. This is not a problem if axis deviation is used in management.

The remodeling potential seen in this study for distal forearm fractures is similar to the remodeling potential described by Ghandi et al. (11), Freiburg (8,9), and Hogstrom et al. (12). These authors showed that an angulation deformity of 10–20° at the distal end of the bone would correct itself with growth. Midshaft remodeling, so far as can be ascertained, has not been described for the human subject. Abraham (1) showed that the midshaft of the radius and tibia of an immature monkey would correct at the rate of 5° per year, or a reduction of 28° could be attained for a 45° osteotomy. Karaharju et al. (13) showed a correction of deformity in dogs from 24 to 12° 160 days after osteotomy in the midshaft of the bone. They felt that the remodeling was partly a physeal event and part subperiosteal new bone formation. This study confirms the existence of midshaft remodeling and demonstrates its relationship with distal shaft correction.

For clinical use, the axis deviation can be calculated using the matrices in Fig. 5. The index may also be calculated by programming a scientific calculator, or using the formula on a computer. In summary, axis deviation allows the pediatric forearm shaft fracture to be managed as one clinical entity. Subdivision into midshaft and distal third fractures is no longer necessary. Errors in the measurement of angulation are reduced, and the remodeling potential of the forearm shaft can be predicted.

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